Structural and Construction Feature of the Hong Kong International Financial Center Phase II

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Abstract

The 88-storey International Financial Centre Tower 2 (IFC2) is no doubt the most eye-catching skyscraper in Hong Kong that erects on the south bank of the Victoria Harbour. The building had been completed and opened for occupation in August 2003.

The IFC2 or Two IFC, with an averaged floor area of about 2300 sq meter, is a composite structure comprising of a RC inner core and an external steel frame supported by 8 mega-columns. In order to stiffen the building against strong wind during typhoon session which is about the summer time of Hong Kong, the structure of the building is strengthened by 4 sets of outrigger systems at a separating interval of about 25 storeys. And of which, 3 set of outrigger systems are provided with special joining devices which can cater for the differential shortening which may occurs between the inner reinforced concrete core and other outer structural steel elements. To support this gigantic building, a 62m diameter cofferdam lined on the side by 1.5m thick diaphragm wall had been built before the foundation was constructed. Two IFC was then founded on a 6.5m thick RC raft seated on bedrock 35m below ground. In addition, the development also includes a 16000 sq meter 6-level podium for retail purposes and a 5-level basement for car parking. The construction of the Two IFC is indeed a splendorous job for engineers and contractors. This paper outlines the structural and construction features of the two IFC. The top-down construction technique for basement construction and the installation of the outrigger system by a retro-installed approach are discussed as well.

Key words: composite structure, mega-column, outrigger system, top-down construction technique

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Introduction

The International Finance Centre (IFC) is an office, commercial, and hotel complex that stands on the harbour front in the Hong Kong Island (Photo 1). The whole development comprises three phases. The phase one construction includes the 38-storey One IFC tower and the IFC shopping center, which has been opened for occupation in 1998. Phase two development comprises a 88-storey office tower named the Two IFC which provides approximately 0.2 million sq m of prime office accommodation together with a six-level podium shopping mall, and a five-level basement which accommodates a train station concourse, car parking and other essential servicing facilities. The two phases of development are connected by two 45m-span bridges. Indeed, the architects have made full use of the space by turning these two bridges into two shopping arcades. The Two IFC was completed in August 2003 and has made the record of the third tallest building in the world. The hotel complex, the third phase of the development, to be operated by the Four Seasons Hotel Group, is due 1for completion in 2004.

It took 2 years for the Two IFC to be completed. The Two IFC was designed by Cesar Pelli, the American architect responsible for the world's tallest building, the Twin Tower in Kuala Lumpur; in association with a Hong Kong architect, the Rocco Yim Design Ltd. Ove Arup & partners were responsible for the civil and structural design of the building and E Man-Sanfield JV construction company Ltd took up the challenge to build it (Tam 2003).

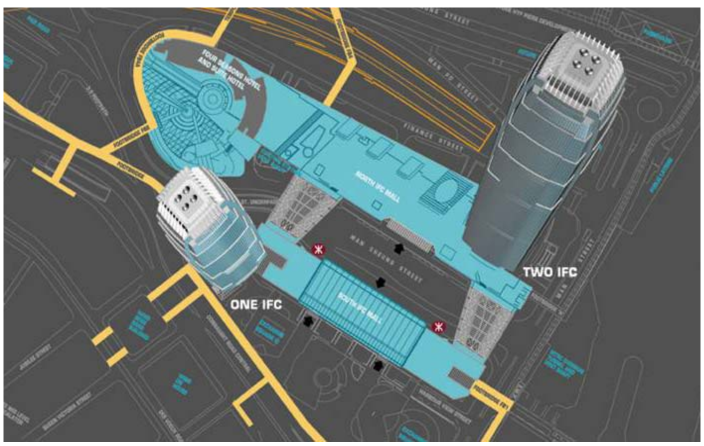


Photo 1 Aerial View of IFC Development (From Ir. David Dumigan – Lecture of IFC for HKPU on 26 Nov 2003)

Structural Features of Two IFC

The highest point of this 88-storey composite tower is +420 mPD where the basement going down to -32mPD. The general footprint of the building is about 57 m x 57 m but at the roof level this area is reduced to 39m x 39m. The gross floor area of this Grade-A office tower is about 180,000 sq m and the typical floor-to-floor height is 4.2m (Photo 2).

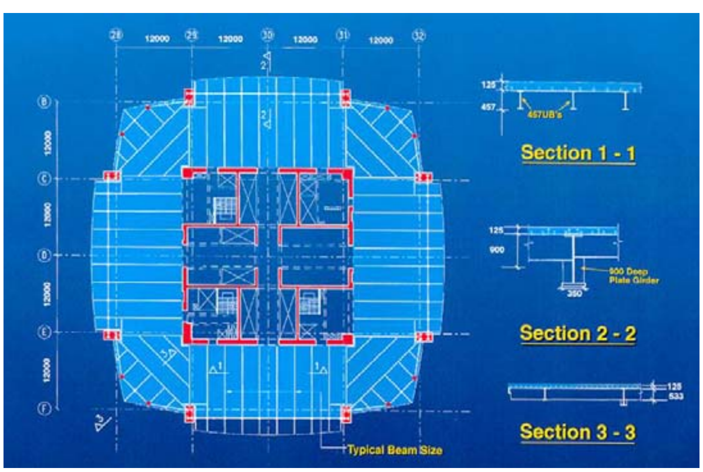
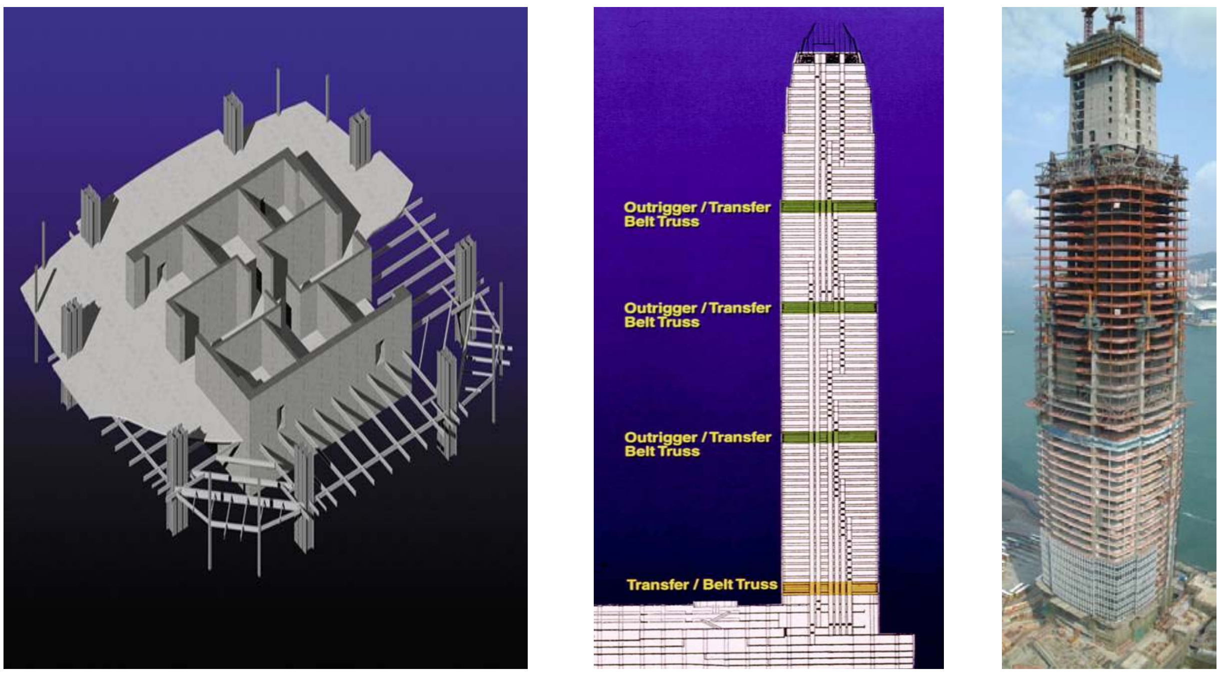


Photo 2 Typical Floor Plan of Teo IFC (From Ir. David Dumigan – Lecture of IFC for HKPU on 26 Nov 2003)

The structural design revolves around four major components (Photo 3), namely (i) the reinforced concrete core wall, (ii) transfer truss/steel outriggers at four levels, (iii) large composite mega-columns, and (iv) 24m primary steel girder beam forming the major structure of the external frame. The design concept is to produce a composite structure with an inner reinforced concrete core wall that acts as a rigid structure. This RC core wall is linked to a structural steel outer frame which is supported by eight composite mega-columns through steel beams and outriggers connections (Photo 4). Two secondary columns are located at each corner of the building to support the gravity load. Composite slabs are used as floor slabs, comprising 460 mm deep steel secondary beams spanning 24m from core wall to the external steel outer frame. Other sets of primary girders with 900 mm depth span between the mega-columns. Four sets of outrigger and belt truss systems are provided to stabilize and strengthen the external steel frame onto the core wall (photo 5). The core wall measures 29 m x 27 m at its base with maximum wall thickness of 1.5 m. The RC wall is made of Grade 60 reinforced concrete. The inner RC core of the building accommodates those primary building functions such as the elevators, stairs, toilets and mechanical rooms that make a 360^0 unobstructed view possible.



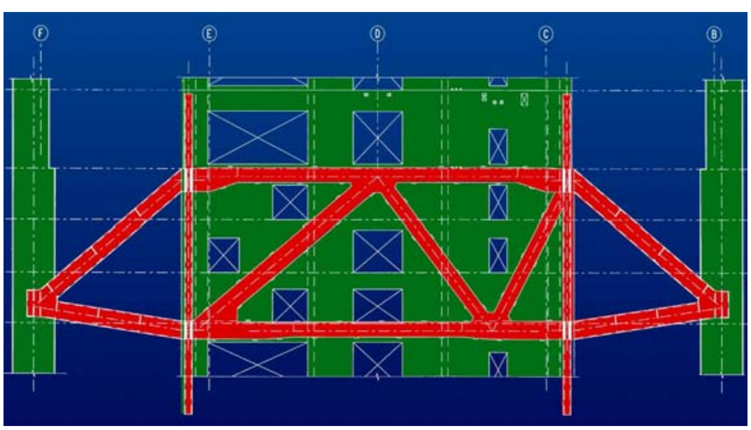
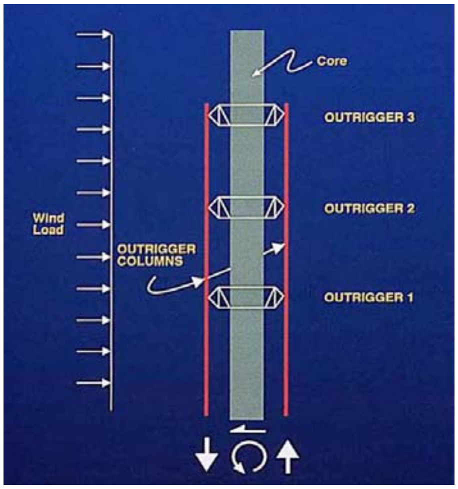


Photo 3 (above) Structural composition of the Two IFC (From Ir. David Dumigan – Lecture of IFC for HKPU on 26 Nov 2003)

Photo 4 (right) Typical Floor Plan (From Ir. David Dumigan – Lecture of IFC for HKPU on 26 Nov 2003)



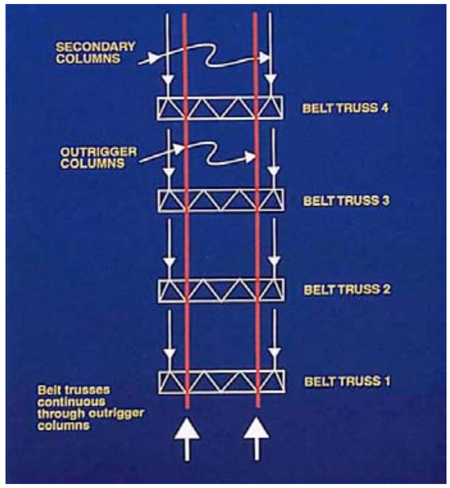


Photo 5 Structural performance of the outrigger and belt-truss systems (From Ir. David Dumigan – Lecture of IFC for HKPU on 26 November 2003)

Foundation system

The provision of a circular cofferdam, as proposed by Aoki Corporation – the foundation contractor, was adopted for the construction of the sub-structure of the Two IFC. Firstly, a circular cofferdam with an internal diameter 61.5m lined with 1.5 m thick diaphragm wall panels was built. The purpose of constructing the cofferdam was to facilitate the excavation and construction of the raft foundation which supports the tower. The design has created what the industry called the biggest hole in Hong Kong (Photo 6).

A majority of the diaphragm wall panels were excavated by the use of hydrofraise, or the reverse circulation trench cutting machine. The average depth of the panels was about 55 m, with the toe grouted and installed with shear pins to ensure their stability.

Photo 6 Cofferdam formed to house the 88-storey tower

Photo 7 Construction of central core on top of the raft

As the excavation proceeded, capping beams at the top of the cofferdam and four ring beams were built for stiffening elements to the diaphragm wall panels. By the provision of a compression ring within the cofferdam, the excavation could be extended safely down to the rock, averaging about 40 m below ground level. The initial excavation was relatively straightforward for merely cutting through reclaimed sand fill layers. However, the later stage of excavation was much more difficult and time consuming as it involved cutting into partially and slightly decomposed granite layers, where a non-explosive demolition agent was used. Meanwhile, a localized depression of the rock level to the south west of the tower base appeared with a maximum depth of rock up to -50 mPD, which was too deep for normal open excavation. In this location, barrettes (rectangular-section piles) were installed to provide support for the raft foundation. The whole excavation process was down to the formation level at -32 mPD. Including the treatment to the localized bedrock, the work took about 16 months to complete.

Immediately from the top of the formation surface, a 6.5m-deep heavily reinforced slab was constructed that serves as the raft for the entire building tower, with a volume of about 20,000 cubic meter of concrete. Starter provisions for the core wall and gusseted bases for the installation of the mega-columns were provided (Photo 7).

The mega-columns

There are eight mega-columns rising from the raft at the base of the cofferdam (Photo 8) up to the roof at 420 mPD, supporting the external frame of the entire building.

Photo 8 Mega-column erected from the raft and anchored on gusseted base

Photo 9 The first set of outrigger and transfer truss system at 6/F (right)

Photo 10 Climb form for constructing the core wall

Photo 11 Girder beam spanning between two columns

The first section of the mega-columns, stretching from basement level 5 to 6/F where the transfer truss is located (Photo 9), has six sub-stanchions formed by 90 mm-thick plates with averaged weights of steel up to 9.7 ton/m. Due to the heavy weight, the stanchions were installed in short sections and connected by welding and non-welded bearing splices. Mobile cranes stationed on the ground level around the cofferdam were used to facilitate the installation process. In order to speed up the work by allowing the mega-columns to be installed at the earliest float, the contract for structural steel works was subdivided into two stages. Contracts were awarded to two independent nominated sub-contractors for installation of the mega-columns, corresponding to approximately 5,000 tons and 19,000 tons of structural steel works respectively.

The mega-columns were encased in concrete, with reinforcing steel bars fixed around the stanchions to increase the strength and stiffness of the columns

The construction of the Core Wall

The construction of the core wall stars from the bottom of the cofferdam. Due to the non-typical nature of the layout and save time in making modification of the form in the confined environment inside the cofferdam, a gang form system composed of timber panel-type shutters stiffened by metal stud was employed. Mobile cranes stationed around the cofferdam on ground level were used to facilitate the installation of the formwork. The construction adopted a bottom-up and floor-by-floor approach, with the vertical wall sections completed first followed by the floor slab until it reached to the ground level. Construction joints were also provided at the sides bounded by the mega-columns to allow separation between the slab and the cofferdam.

Starting from the ground level, another set of steel shutter form was used to replace the original timber panel-type one, up till it reached the 3rd floor level. From the 4th level onward, the form was modified with the adding in of a girder frame, hydraulic jack and clamp system, and to transform it into a climb form. In order to achieve more effective operation, the core wall was sub-divided into 2 phases using 2 independently controllable form systems (Photo 10), with construction jointing in the middle where the tie members located. Floor cycle for typical floors were maintained at 4 to 5 days, with certain expected delay in floors where the outrigger system located or the wall started to reduce size.

The Superstructure of the Two IFC

The Two IFC relies on an outrigger truss lateral stability design. The outrigger truss connects the rigid inner RC core wall on the one end, and on the other end links to the external steel frame. The floor system makes use of 125 mm thick composite slabs supported on steel beams. To allow for unobstructed panoramic views along the external wall, a deep edge girder spanning up to 24 m is provided to support the floor between the main columns (Photo 11).

The mega-columns are of a concrete-encased composite design, rectangular in section with the narrow side facing outward to minimize visual obstruction. These columns are composed of six I-section columns (sub-stanchions) arranged in three pairs for the lower floors, and reduced to three, two and one in number for the upper floors. They are used as the main load bearing structural elements for the exterior frame of the two IFC. In order to reduce costs and increase stiffness of the columns, reinforcement bars ranging from 4 per cent to 2 per cent of the column section are positioned around the perimeter of the stanchions. The encasing concrete used for the columns is of grade 60 (Basement up to 52/F) and grade 45 (53/F and above). One self-climbing form system was used for the concrete encasement works at the mega-columns (photo 12 and 13).

Photo 12 External mounted climb form for casting the mega-columns

Photo 13 Detail of the form in its opened mode

Other spectacular features of the superstructure are the belt truss and outrigger systems. The first set of the belt truss system is located on 6/F and 7/F that transfer and spread the load of the columns from the upper structure down to the mega-columns. Meanwhile the other three sets of outrigger systems, located on 32/F-33/F, 53/F-54/F and 65/F-66/F respectively, served as strengthening components to improve the rigidity of the structure and to reduce the effect of deflection on the building due to wind load. The outrigger and belt truss systems in general include a built-in inner steel frame serving as an anchor truss, which is embedded in the RC core using a two-stage casting (retro-installation) process (photo 14), and an external frame in the form of belt truss acting as an external stiffening member as well as to take up the gravity loads from the corner columns (photo 15).

The outriggers and the belt trusses are connected by adjustable joints located inside column slots, which allow dimensional-toning with a series of packing shims (Photo 16). This design is to cater for the differential shortening between the RC core and the perimeter columns during construction of the tower as well as the slight shortening that occurs throughout the life span of the building. This design concept was originally used in the construction of the Cheung Kong Center (Photo 17).

Photo 14 Inner frame as anchor for the outrigger system

Photo 15 Encasing the anchor frame in a retro-approach

Photo 16 Jointing between outrigger and mega-column

Photo 17 Outrigger design used in the Cheung Kong Center

Top-down Construction Techniques for the Basement Construction

The 38,000 sq m, five-level basement beneath the podium was constructed using a top-down construction technique. Firstly, the steel stanchions were positioned into the bored piles and connected to the foundation by gusset plate. The stanchions had supported the upper basement slabs when the excavation and casting process proceeded. Couplers were welded to the sides of the stanchions at levels where the basement slab was located. Having considered the scale of the basement, the basement construction work was constructed in nine main phases in order to confine the construction to controllable segments. It took 18 months to complete the basement construction.

Removing the huge amount of excavated spoil was one of the problems during the construction process. To tackle this problem, three temporary access shafts were developed on the slab of the basement, located on the east, middle and west portions of the podium plinth respectively. The shafts were used to transport the spoil from the excavation point vertically to the ground surface (Photo 18). At the same time, specially designed rack-type lifting devices (material hoists) equipped with 3 cu m tilted bucket was installed at each shaft to remove spoil efficiently and quickly from the basement. For horizontal transportation, a temporary unloading pier with an elevated linking bridge was provided on the nearby seawall to allow dumping vehicles to remove spoil from the site and unload them onto barges.

In order to expedite the excavation and casting works as well as to provide sufficient headroom for the use of excavating machines, a double bit method was adopted to construct the basement slab. Two level of basement were excavated at a time and then cast the slab of the lower basement in an advanced phase. From the completed slab, the slab above was constructed first. The completed slab thus facilitated the erection of propping work for the upper slab, and could also be used as a separating plate to allow excavation for the lower floors (Photo 19).

The critical work in the construction of the basement was the breaking through between the podium and the main tower portions, as well as part of the basement area linking between Phase I and Phase II. The diaphragm wall panels that formed the cut-off wall of the cofferdam under the footprint of the main tower were demolished by pneumatic breakers as the excavation proceeded in a top-down sequence. The panels separating Phase I and Phase II were removed with the saw-cutting method, where the concourse of the Mass Transit Railway's Hong Kong Station could be linked.

Photo 18 Temporary shaft for removing excavated spoil

Photo 19 Typical double-bit construction arrangement

Construction Features of the Two IFC

As a world-renowned project, Two IFC has adopted a series of innovative concept in the design and construction of the building, these features include

- Provision of on-site concrete batching plant to satisfy consistent supply of large amount of concrete for daily consumption.
- Construction of two retail bridges linking the Phase 1 and 2 podiums by the use of prefabricated steel truss that hoisted to roof level for further erection by strand jack system (Photo 20).
- Use of circular cofferdam to avoid complicated shoring arrangement during sub-structural works.
- Apply top down approach for the six-level basement construction.
- Use of hydraulic climb form systems for the encasing of the mega-columns.
- Use of prefabricated stairs.
- Use of fire-resisting partition wall for most of the internal walling to avoid wet trade and to reduce load (Photo 21).

Photo 20 Construction of the link bridge

Photo 21 Dry wall installed as fire-resisting partitions

Lesson learnt from Other Tall Buildings

After the tragedy of September 11, safety of tall buildings especially on the building and structural design aspect is a crucial concern for high-rise buildings. It is the prime duty of the engineers to put safety (evacuation) into the first priority. Seven safety features are adopted in the design in Two IFC, which further assure the safety use of the building.

- The composite nature of the building with major structural/load-taking elements encased in concrete can have very good endurance during fire.
- Four escape stairs are provided to allow for swift evacuation.
- Maximum evacuation time is designed to be within 22 minutes.
- Pressurized staircases create smoke free environment.

- Four refuge floors are provided which served also as a fire-breaking storey.
- Two high-speed firemen lifts were provided, which can make access to the top floor within 60 Seconds.
- Dual Telecom and power supply system are employed to ensure communication and operation of essential services during emergency.

Conclusion

The construction of such a super high-rise building presents a range of practical problems beyond a layman's imagination. For example, at the peak of the construction period, there were more than 1,200 workers coming from 50 different trades working at the same time on the site. Daily consumption and delivery of materials to the site could be as much as 300 tons per day, with cash flow close to US$15 million per month at its peak. Transporting heavy building components such as those for the outriggers or mega-columns, some with weight as heavy as 15 tons, has also created challenges in the project planning and construction stages.

The success of running the project in such scale indeed is a great challenge to the contractor in terms of project management, construction engineering, safety management, quality control, and value management. The accomplishment of the Two IFC sets a landmark for the achievement of the Hong Kong's construction industry.

Reference

1. "Enter the Megatowers", New Civil Engineer International, July 2001
2. Gibbons C., Lee A.C.C., MacAuthur J.M., Wan C.W., "The Design and Construction of Two International Finance Centre", Advances in Building Technology, Volume 1, 2002.
3. Angela Tam, "Practical drama: user-friendly space in a New Landmark", Hong Kong Engineer, January 2003
4. David Dumingan (2003) Design and Construction of Two IFC. Lecture for Hong Kong Polytechnic University. 26 November 2003